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Sensation of movement

An introduction

Thor Grünbaum and Mark Schram Christensen

This book is about the sensation of movement and the role of these sensations in motor control, sense of agency, and bodily self-recognition. Sensations of movement are the conscious impressions of bodily movement that a person normally has when she moves her body (for instance, when she is walking) or a part of her body (for instance, raising her arm). Movements of a person's body or a part of her body come in both active and passive varieties. As we shall see, it is an open question whether the sensations of movement should also be divided into active and passive types. In certain situations, the sensations of movement might be sufficient to make a person believe that her body is moving (for instance, a vibrator applied to the tendon of the tibialis anterior muscle of a relaxed seated person can give her an illusory sensation of plantar flexion of the foot, see [Roll & Vedel, 1982](#)). It might even be possible to create the sensory impression of active movement. Studies using direct electrical cortical stimulation during surgery ([Desmurget et al., 2009](#); [Fried et al., 1991](#)) indicate that participants can experience an urge to move related directly to sensations of movement. These latter results remain contentious. One reason for being skeptical about the existence of "active movement sensations" is the fact that it is unclear what kinds of information give rise to the sensations in question. Afferent information from muscles, tendons, and skin plays obvious roles. But what about motor commands and predicted afferent feedback computed from the commands? And how do these various sources of information interact in cases of informational consistency and conflict?

The sensations normally associated with movements have for a long time been of central interest in the domains of modelling-based approaches to motor control, psychology of bodily self-recognition, and philosophy of action. Although there is consensus that moving agents have sensations of movement, and that these sensations play important roles in movement control and cognition, there is little agreement about what these roles are and how sensations play these roles. The present volume is motivated by this lack of agreement in the cognitive sciences and philosophy. Our aim with the present volume is not to settle these disagreements once and for all, but to highlight some of the sources for the missing consensus and provide some of the groundwork for further progress. We do this by addressing three fundamental aspects: (1) The content of conscious sensations of movement, (2) experimental designs and measures, and (3) the possible functions of proprioceptive and kinaesthetic information in motor control and bodily cognition.

Models and theories of the role of sensations of movement in motor control and self-attribution of action and body are characterized by a tension between, on the one hand, the seemingly innocuous intuition that sensations of movement are important to motor control and bodily self-recognition and, on the other hand, striking experimental results and theoretical considerations that raise doubts about this intuition. Let us elaborate this point. On the one hand, it feels like something to move one's body, and it seems as if these sensations are important for the normal performance of controlled movements, self-attribution of actions, and bodily self-recognition. This importance can be inferred from cases where the normal sensations of movement are absent or somehow diminished. On the other hand, well confirmed experimental results (e.g. [Longo & Haggard, 2010, 2012](#)) and weighty theoretical considerations challenge this inference (for discussion, see Wong, Present volume, chapter 7). Given these results and considerations, it is no longer clear that the conscious movement sensations could play these significant roles. In this brief introduction, we will articulate this tension and place the various chapters of this volume with respect to it.

It is a strong intuition that normal functioning of motor control and self-recognition relies on conscious sensations of movement. Let us here mention three types of evidence that seem to justify this intuition. First, cases of deafferentation indicate that motor functions suffer dramatically when agents are no longer able to feel their bodily movements. This is famously demonstrated by the case of IW (see [Cole, 1995](#)). As a young man, IW lost all sensation of movement from his neck and down. At first, he lost his ability to control his movements, even though he had suffered no damage to his efferent motor system. Although he never recovered his sensation of movement, through hard and extensive practice, he slowly regained some abilities to control his movements. Importantly, IW's motor control abilities appear to be qualitatively different from

normal motor control (for a careful discussion of deafferentation, see Wong, Present volume, chapter 7). Thus, losing the sensation of movement seriously alters abilities to control one's movements.

Second, damage to brain structures involved in control of movement and sensation of movement can give rise to striking alterations of self-attribution of action and body parts. Some patients, suffering from complete contralesional hemiplegia, deny their brain damage and claim to have intact motor abilities (anosognosia for hemiplegia). It has recently been proposed that this phenomenon could be explained by patients having illusory sensations of movement produced by a malfunctioning motor control system (Berti & Pia, 2006). Thus, non-veridical sensations of movement might produce self-attribution of action in patients that are unable to move.

Third, certain psychopathological delusions have been linked to altered motor awareness and altered self-recognition (e.g. Frith, 2005). This has been the general framework for one popular way of explaining delusions of alien control in patients with schizophrenia. According to this type of explanation, delusions of alien control can occur when the patient's sensation of voluntary movement are somehow indistinguishable from sensations of passive movements. A certain sense of agency is missing. Consequently, the patient can come to believe that her movements are controlled by some alien force. Pathological changes to the sensations of movement are thus thought to be involved in the misattribution of agency.

A natural conclusion to cases such as these is that sensations of movement play important roles in normal motor control, sense of agency, and bodily self-recognition. However, when we try to articulate what exactly these roles might be, problems start to occur. Here we will briefly discuss three types of considerations that raise doubt about the acceptability of the intuition that sensations have important functional roles in movement control, sense of agency, and bodily self-recognition. This sets the scene for the chapters of the present volume.

First, it is unclear how we should describe the content of the experience in question. What is the content of the sensations of movement? One way to understand the notion of content is by imagining a situation where all "naturally occurring" sources of sensory information are screened off. Suppose that in this state we can artificially induce in a person (say, by vibrating tendons or by direct cortical stimulation) the types of information sufficient for creating the subjective illusion of bodily movement. If the person is ignorant of the artificial situation, would these artificially induced streams of information suffice to make her believe that she is moving a specific body part? If they do suffice, that would be a good reason to describe the sensations as representing a particular kind of movement, say, a movement of her right foot. In the same way, we can ask whether the sensations represent the movement as being active or passive.

In contemporary cognitive neuroscience, the issue is often phrased in terms of the distinction between sense of ownership and sense of agency (see Gallagher, 2000). According to this distinction, bodily movements are always experienced with a sense of ownership irrespective of whether they are passive or active. In addition to the ownership experience, active movements are also experienced with a sense of agency. We can now ask whether the sense of agency is part of the sensory content related to the movement or a higher cognitive construct (or both – maybe there is a low-level "actish feel" built into the sensations of active movements as well as a higher-level sense of agency related to planning and decision-making). As long as we do not have a clear grasp of how to describe the content of the sensations of movement, it is hard to know whether sensations could play important explanatory roles in motor control and sense of agency.

The first two chapters address important questions about the content of the sensations of movement. In chapter 1, Andreas Kalckert takes a closer look at the distinction between sense of ownership and sense of agency. This distinction has been important in conceptualising results from "rubber hand" experiments. The standard paradigm uses a static motionless setup. The chapter investigates whether we can manipulate sense of ownership and sense of agency in versions of the paradigm where participants are moving. In chapter 2, Myrto Mylopoulos argues that bodily sensations of movement can represent the movement as active. According to Myrto Mylopoulos, this question is parallel to questions about the nature of the content of visual perception. Some people defend a sparse view according to which vision can only represent visual features such as shape, orientation, and colour, whereas other people defend a rich view according to which vision can also represent categories such as "chairness" or "elephantness". Similarly, according to a sparse view of sensations of movement, the sensations represent only kinematic features; by contrast, according to a rich view, the sensations represent also "jerkyness", "smoothness", "activity", and "passivity".

Second, it is unclear how to experimentally measure and manipulate these sensations and their supposed “activity” feature. How can we be certain that sensations of movement play important roles for control and recognition if we have no good way of measuring and manipulating them? It is possible that it is not by virtue of being conscious that certain types of sensory information are important to movement control. Furthermore, it cannot be ruled out that the sense of agency that is supposed to play a role in action attribution is reducible to higher-level cognitive processes such as conscious planning, deliberation, and decision-making (for discussion, see Grünbaum, 2015; Mylopoulos, 2015).

Chapters 3 and 4 take up these important methodological questions. In chapter 3, Mads Jensen, Mia Dong, Mikkel C. Vinding and Morten Overgaard address the issue of how to measure the sense of agency. They review the most important measures in the experimental literature. Importantly, they also present some of the early results of their work on developing a subjective scale of sense of control. In chapter 4, Mark Schram Christensen and Thor Grünbaum raise another methodological problem for the experimental sense of agency literature. By reviewing the dominant experimental paradigms, they show that most existing studies investigate ways in which agents bring about effects in the immediate environment. Dominant paradigms are therefore *not* suited for investigating the sense of agency related directly to bodily movements. The existing literature in cognitive neuroscience can therefore not be used to say anything substantial about whether or not sensations of movement represent the activity of the movement.

Third, it is unclear that proprioceptive information has the required precision to play a central role in motor control. It seems intuitively correct that one type of proprioceptive information important for control of movements is information about the position of the body parts. In a series of experiments, Longo and Haggard (e.g. Longo & Haggard, 2010, 2012) have demonstrated that this information is subject to systematic distortions. Furthermore, it has been demonstrated how easily this information can be manipulated and how prone we are to experience various kinds of body illusions (see, for instance, Kalckert & Ehrsson, 2014). If these results do not directly undermine the intuition that sensations of movement have important motor control functions, they do at least seriously qualify the possible roles these sensations could play.

The last group of chapters attends directly to these questions. In chapter 5, Anne Kavounoudias reviews experimental literature studying the various sources of information involved in sensations of movement. A plurality of sensory modalities is involved in generating sensations of movement. This plurality of sensory streams can give rise to various kinds of informational redundancies and conflicts. By drawing on physiological, neuroscientific, and psychophysical research, Anne Kavounoudias argues for a Bayesian model of the sensation of movement as a kind of multimodal perception based on cross-modal interactions rather than an a-modal perception as previously suggested by James Gibson in the 1960s. In chapter 6, Matthew R. Longo reviews research on distorted body representations underlying position sense. Recent research has revealed that both tactile size perception and position sense rely on highly distorted representations of the body. The presence of such distortions raises a fundamental problem. The lack of proprioceptive afferent information is known to cause devastating impairments in skilled action, suggesting that position sense plays a critical role in skilled action. Mathew R. Longo sketches an answer to the basic question of how skilled action can co-exist with distorted representations of the body. In the final chapter 7, Hong Yu Wong systematically articulates this basic conflict. According to Hong Yu Wong, we cannot respond to this conflict by discarding proprioception from motor control because we know from the severe problems deafferented agents face in acting that ordinary action requires proprioception. The solution, he proposes, is that the possibility of bodily action is provided for by multimodal body representations for action. Hong Yu Wong’s proposal is supported by the kind of Bayesian model proposed by Anne Kavounoudias.

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